CLEMENTINE IMAGES OF THE LUNAR SAMPLE-RETURN STATIONS: IMPROVEMENTS TO THE TiO_2 MAPPING TECHNIQUE.

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Introduction. This report represents part of our continuing effort to develop and refine a method for determining the TiO_2 content of the lunar surface using extended-visible reflectance spectrometry. The technique for Ti [1, 2] was developed using global low-resolution (~35 km/pixel) Clementine UVVIS camera image products, and has also been applied to Galileo SSI images of the Moon. Our goal is to develop a calibration for the full-resolution UVVIS images using images of the sample-return sites. Doing so increases the number of calibration points, since for Apollo 15-17 individual sampling stations can be resolved in most cases.

The images used here were prepared in the Integrated Software for Imaging Spectrometers (ISIS) system developed by the U.S. Geological Survey, using standard routines designed for the Clementine UVVIS camera. The processing scheme, similar to that described by [3], includes gain and offset correction, exposure time normalization, dark current and readout time correction, pixel sensitivity non-uniformity (flat-field) correction, long and short exposure merger, registration of the A (415 nm), C (900 nm), D (950 nm) and E (1000 nm) filter images to the B (750 nm), photometric correction ([4] and more recent updates), geometric control using information stored in the image SPICE labels, conversion to orthographic projection at 125 m/pixel spatial resolution, and mosaicking of the resulting 5-band cubelets. Finally, the images were converted to "absolute" reflectance by dividing by the spectrum of the Apollo 16 telescopic site extracted from the Clementine images, then multiplying by the laboratory spectrum of Apollo 16 soil 62231.

For Apollo 11-14, and Luna 16-24, landing sites were located in the image cubes by a combination of pixel latitude/longitude coordinates provided by the ISIS image display program QVIEW, landing site maps, orbital photography, NASA Preliminary Science Reports, and other published reports. For these sites, an area of typically 11 x 11 pixels centered on the landing site was averaged to produce the 5-point reflectance spectrum. At Apollo 15, 16, and 17, landmarks make the sites readily identifiable. Traverse maps were used to locate the sampling stations. For most stations, 3 x 3 pixel boxes were averaged. In a few cases slightly larger areas were used where two stations are located close together. The data set contains eight stations at Apollo 15, seven at Apollo 16, and nineteen (including rover stations) at Apollo 17.

Soil composition data for <1mm fines was compiled from previous literature, chiefly [5] and sources therein. For Apollo 11-14 and the Luna sites, representative averages of soils were used for the site value. Individual sampling station values were used for Apollo 15-17.

TiO_2 Analysis. To examine the effects of spectrally neutral opaque (SNO) phases such as ilmenite on the reflectance characteristics of the lunar surface, a plot showing the 415/750 nm ratio and 750 nm reflectance for each site or station was constructed (Fig. 1). Here two trends are evident, one related to ilmenite variations in the maria, the other to FeO and maturity changes in the highlands. Ilmenite is dark and has a relatively flat spectrum from the near-UV to near-IR. Therefore, ilmenite-rich soils are "blue" relative to typically reddish lunar materials, and plot towards the upper left in Fig. 1 (low reflectance, high 415/750 ratio). Rotating the coordinate system clockwise through an angle a projects the spectral variations caused by SNO onto the y-axis. A spectral opaque parameter is thus defined by {(refl. @ 750 x [$\sin(\alpha)$]) + (415/750 x [$\cos(\alpha)$])}. We found the highest correlation between the parameter and soil TiO_2 content at $\alpha = -30^\circ$.

Fig. 2 is a plot of sample-return station TiO_2 vs. the opaque (Ti) parameter. The correlation coefficient is 0.91, and the equation of the best-fit line is TiO_2 wt.% = (105.479 x Ti-param.) - 40.005.

It is anticipated that continued improvements to the Clementine photometric calibration, particularly in the A (415 nm) filter, will improve the fit of the spectral parameter to the laboratory compositional data. In Fig. 2, points for Apollo 15 and Apollo 17 appear to have Ti-parameter values that are slightly low. These two landing sites are at relatively high latitude, which for Clementine corresponds to larger phase angles of the observations. The current photometric function produces 415/750 nm ratio values that are too low at these higher latitudes (Fig. 1).

Luna 24. Luna 24 continues to be something of an anomaly. Fig. 2 indicates that the Luna 24 site has a Ti-parameter that is higher than expected for the TiO_2 content of the soil returned from that site (mare basalt with ~1 wt.% TiO_2). The high parameter value is mainly caused by a high 415/750 nm ratio, and is indicative of material with 3-4 wt.% TiO_2. Laboratory spectra [6] of the Luna 24 samples have the lowest 400/560 nm ratio of any measured mare soil, consistent with their low TiO_2 content. The remote-sensing evidence (ground-based [7], Galileo, and Clementine) implies that either Luna 24 did not land at the reported location, or that the sample it collected is non-representative of the lander's surroundings.

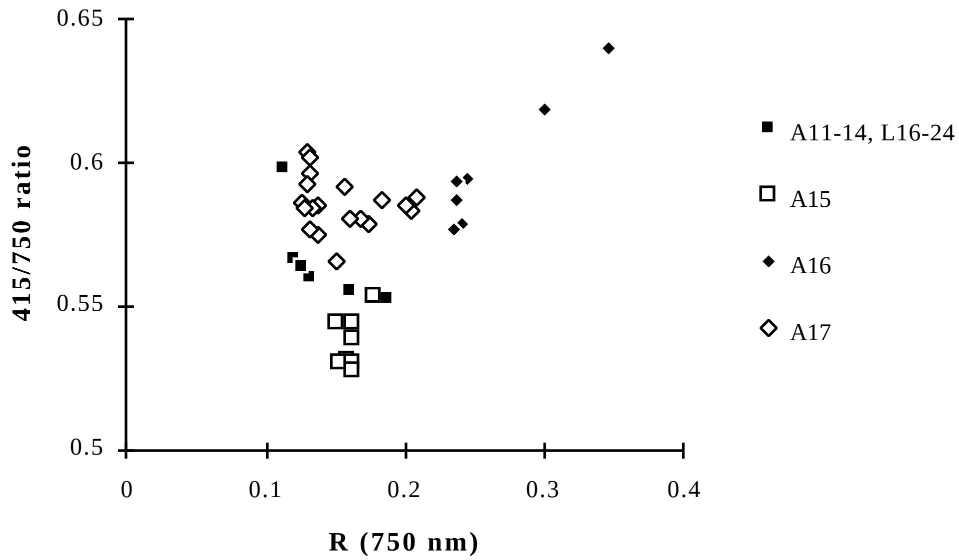

Figure 1. UVVIS ratio-reflectance plot for lunar sample-return sites and stations.

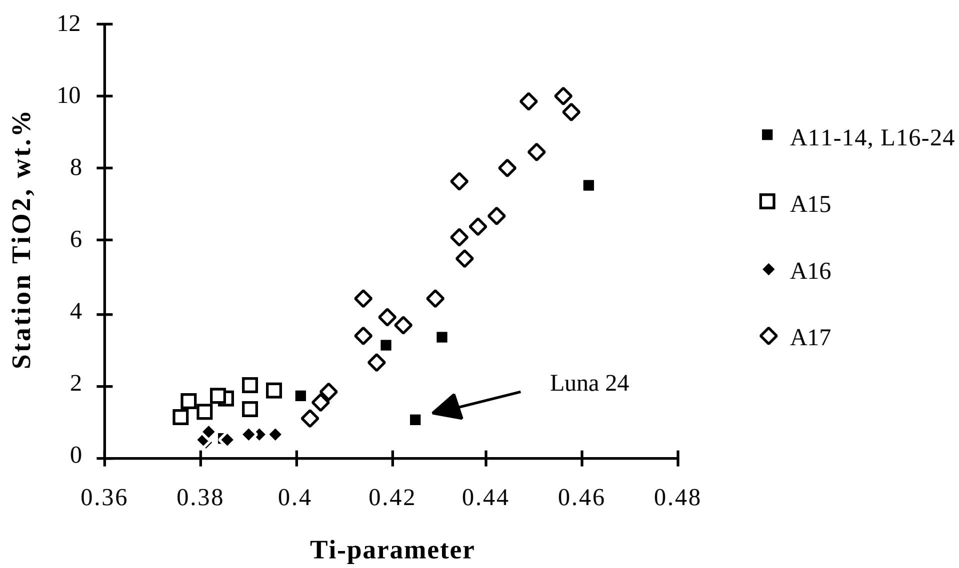

Figure 2. Plot of sample-return site or station TiO_2 content vs. the Clementine Ti-parameter.

References: [1] Lucey *et al.* (1996) *Lunar Planet. Sci. XXVII*, 781. [2] Lucey *et al.* (1997) *J. Geophys Res.*, submitted. [1] Pieters *et al.* (1994) *Science* **266**, 1844. [4] McEwen (1996) *Lunar Planet. Sci. XXVII*, 841. [5] Korotev (1981) *Proc. LSC 12th*, 577; Korotev, (1987) *Proc. LPSC 17th*, E411; Korotev and Kremser (1992) *Proc. LPS 22nd*, 275. [6] Adams and Ralph (1978) in *Mare Crisium*, 81. [6] Pieters *et al.* (1979) *Proc. LPSC 10th*, 2967.